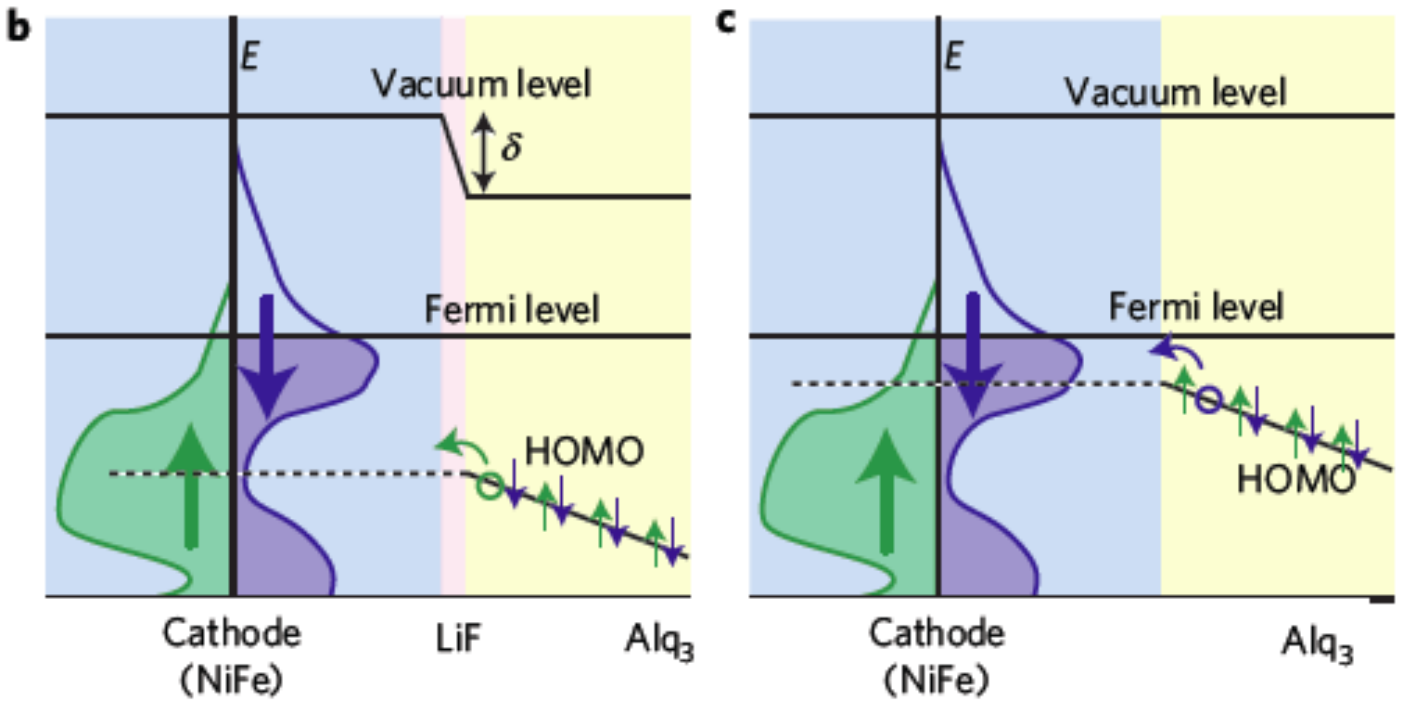
# MR sign reversal in various spin valves and tunnel junctions (non-ferroelectric)

Yuewei Yin

04/07/2017

Prof. Xu’s group meeting

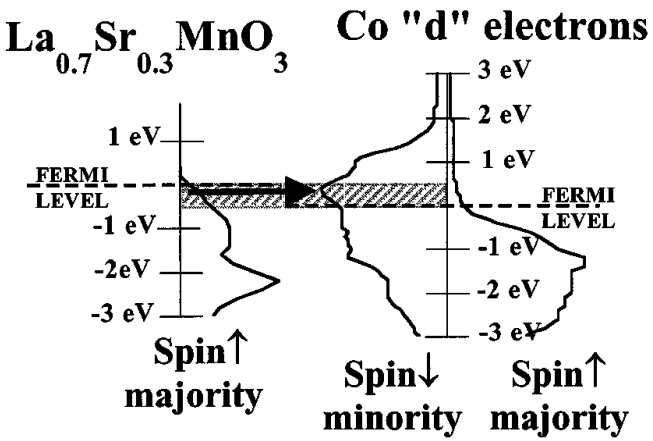
# Band alignment

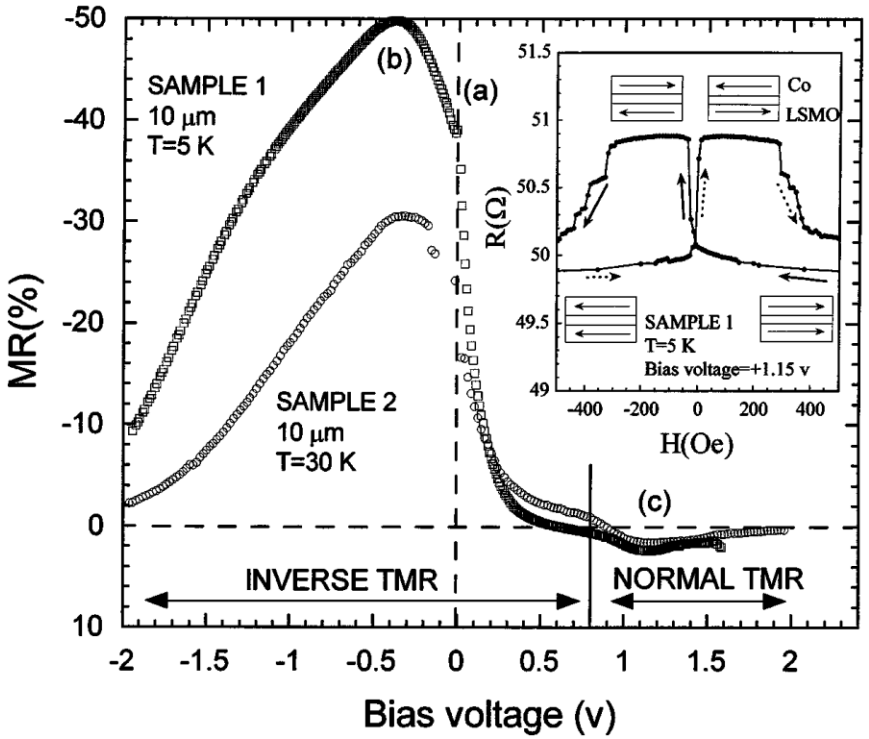


20 μm

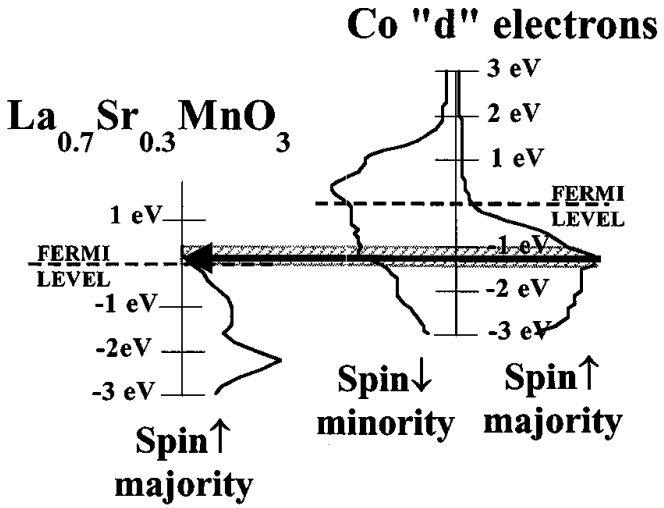
# LSMO(35nm)/STO(2.5nm)/Co(30nm)/Au(5nm)

(b) V=-0.4 V

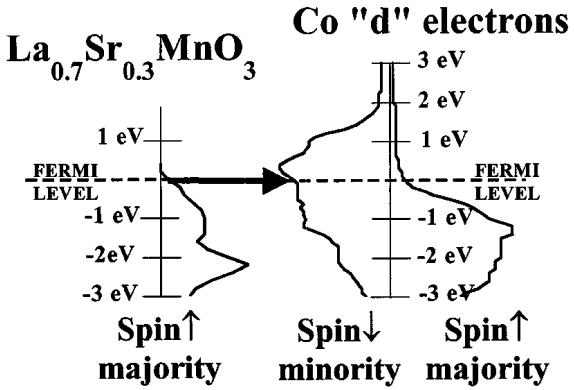



(c) V=+1.15 V




(a) V=0

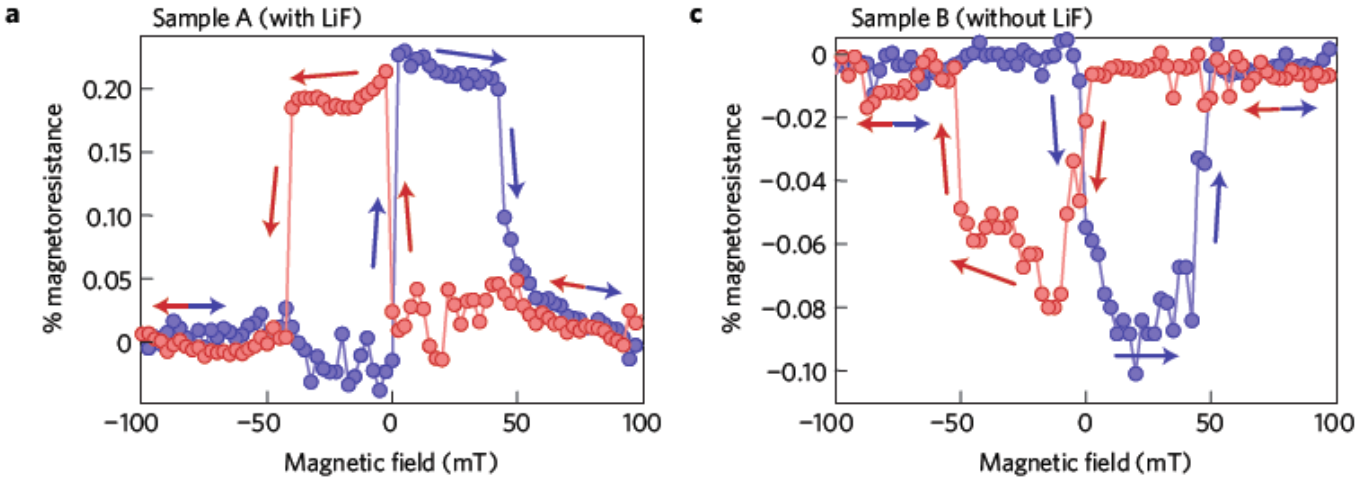


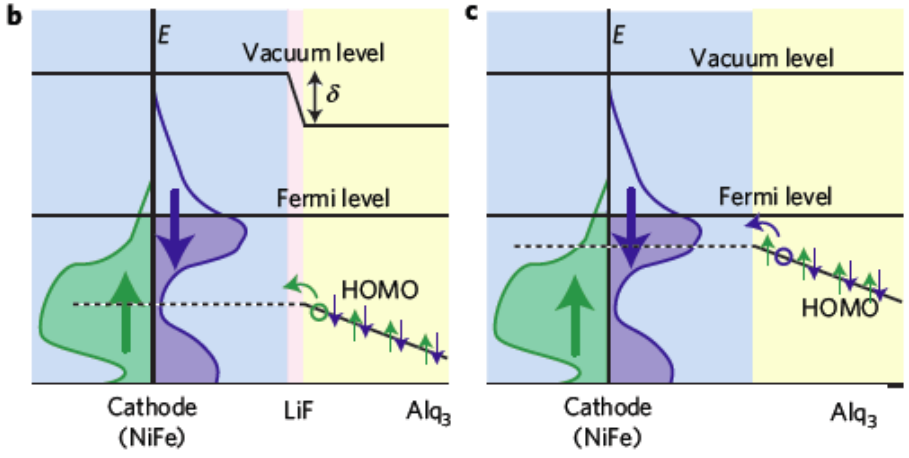

Bias dependent MR is related to the Co band alignment.

PRL 82, 4288 (1999)

$1-2\ mm^2$

# FeCo(17nm)/Alq3(150nm)/LiF(1nm)/NiFe(20nm)



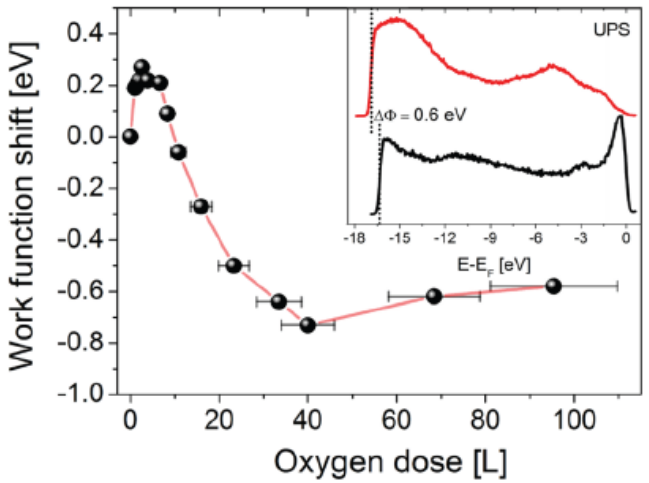



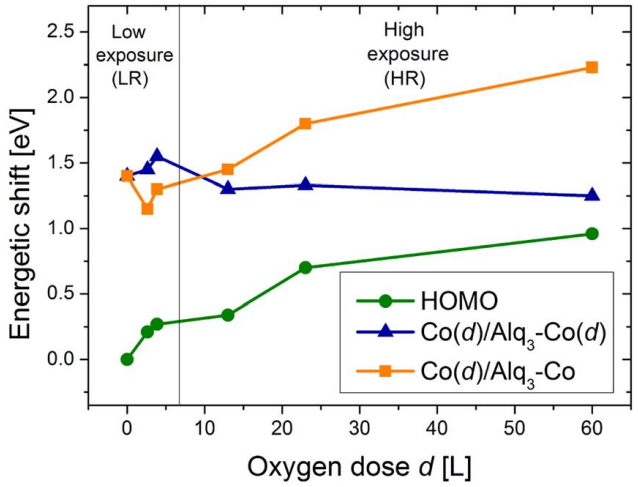

LiF reversed MR sign

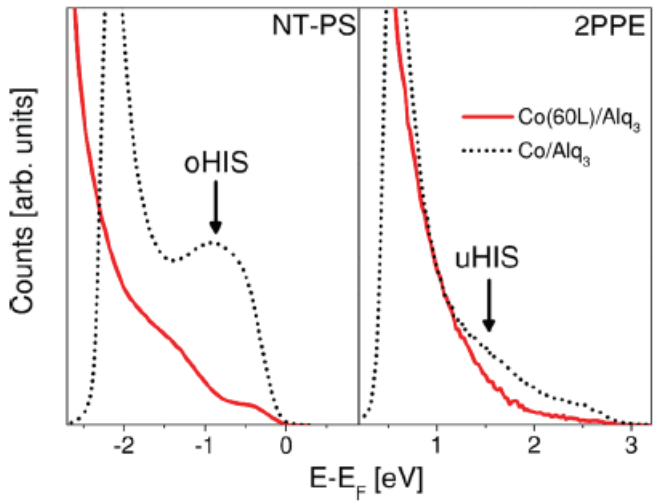
Polar interface shifted the band alignment.

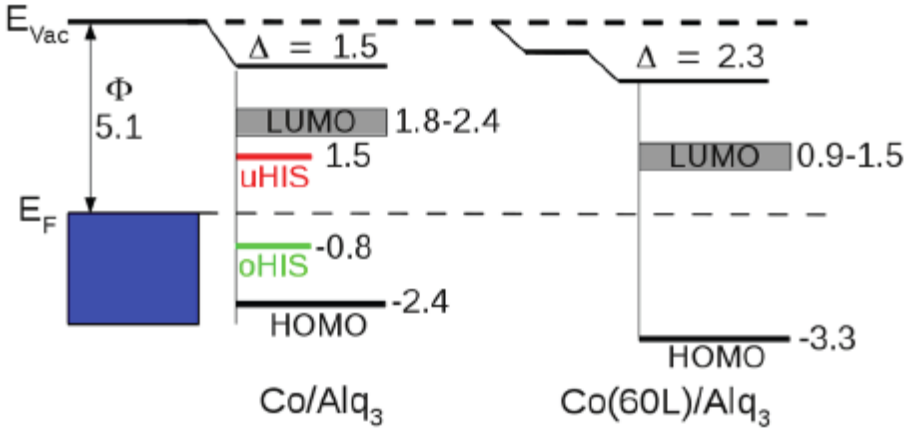
NatMater 10, 39 (2011)

# Band shift with CoO forming



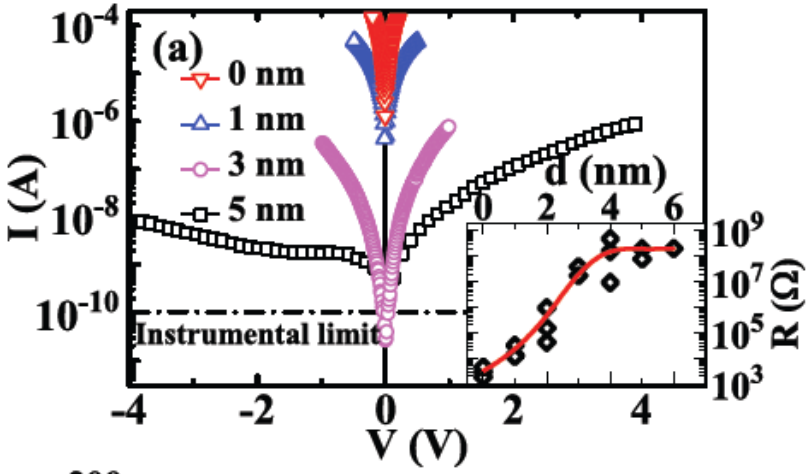



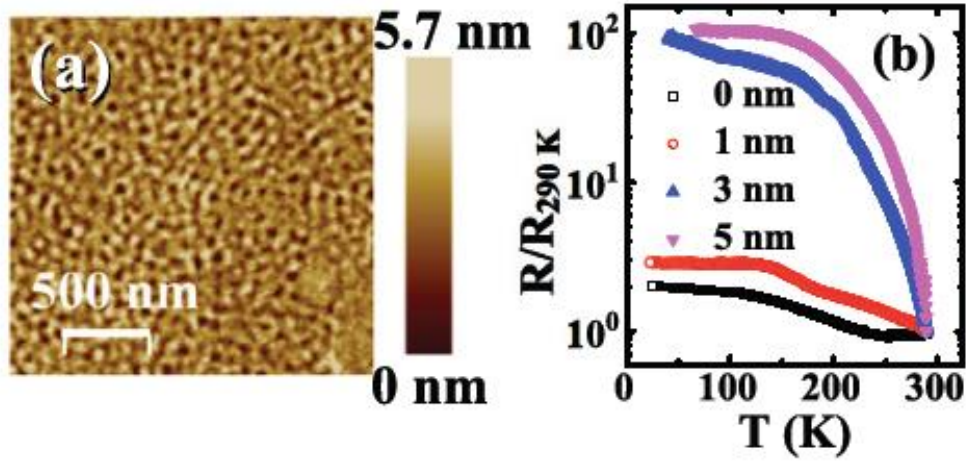

- CoO dipole shifts the band.
- More CoO, more shift.

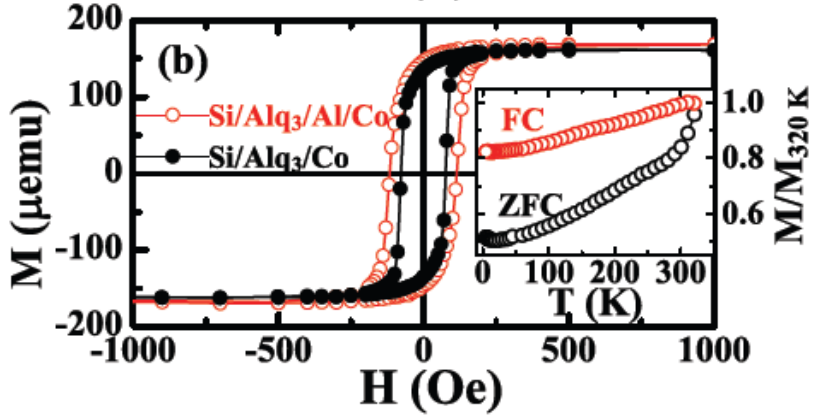
APL 103, 262402 (2014)

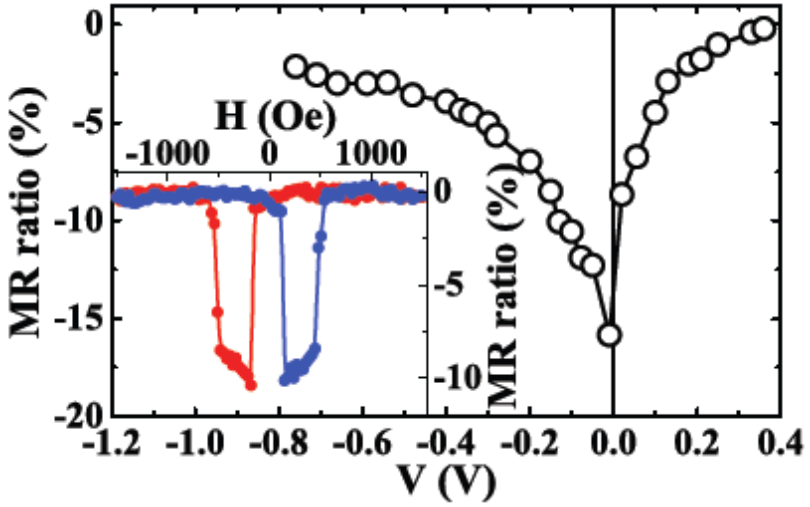
~0.2 mm × 0.2 mm

# LSMO(50nm)/Alq3(30nm)/Al(0-6nm)/Co(20nm)



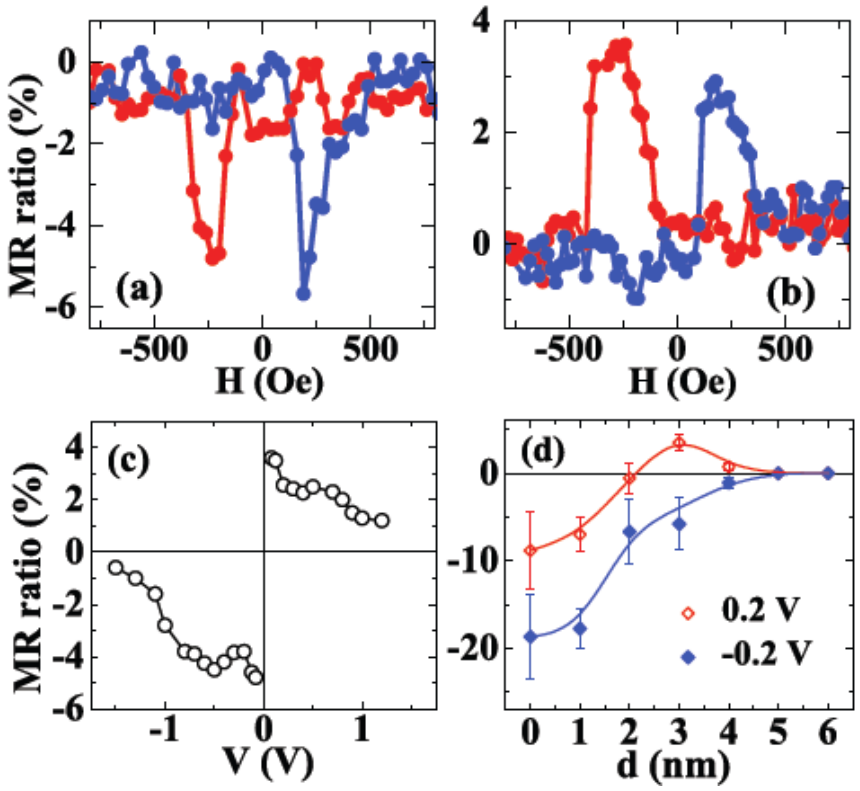



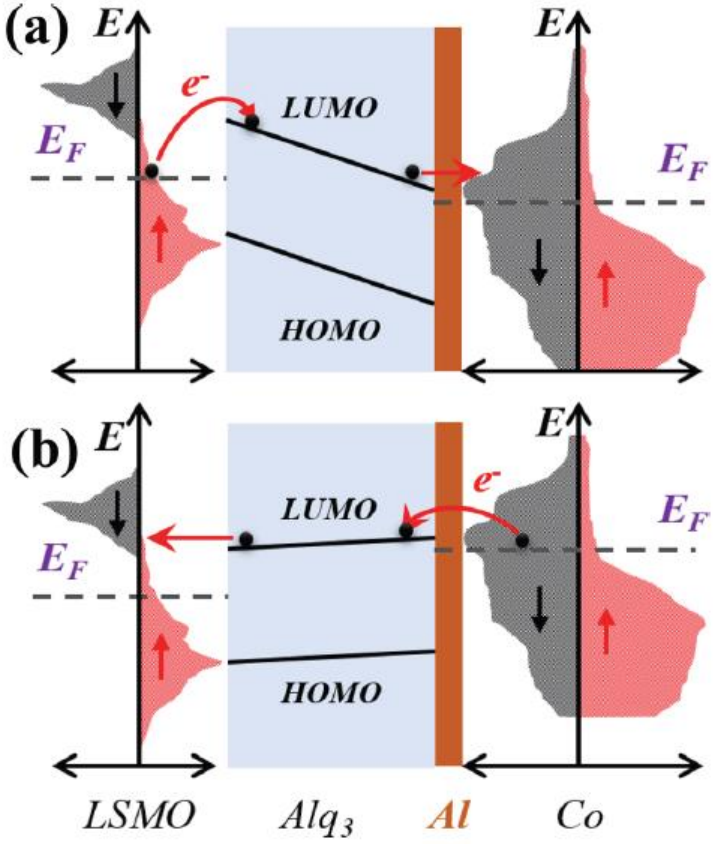

0nm Al: Negative MR ratio decays faster as increasing positive voltage

APL 104, 262402 (2014)

~0.2 mm × 0.2 mm.

# LSMO(50nm)/Alq3(30nm)/Al(0-6nm)/Co(20nm)



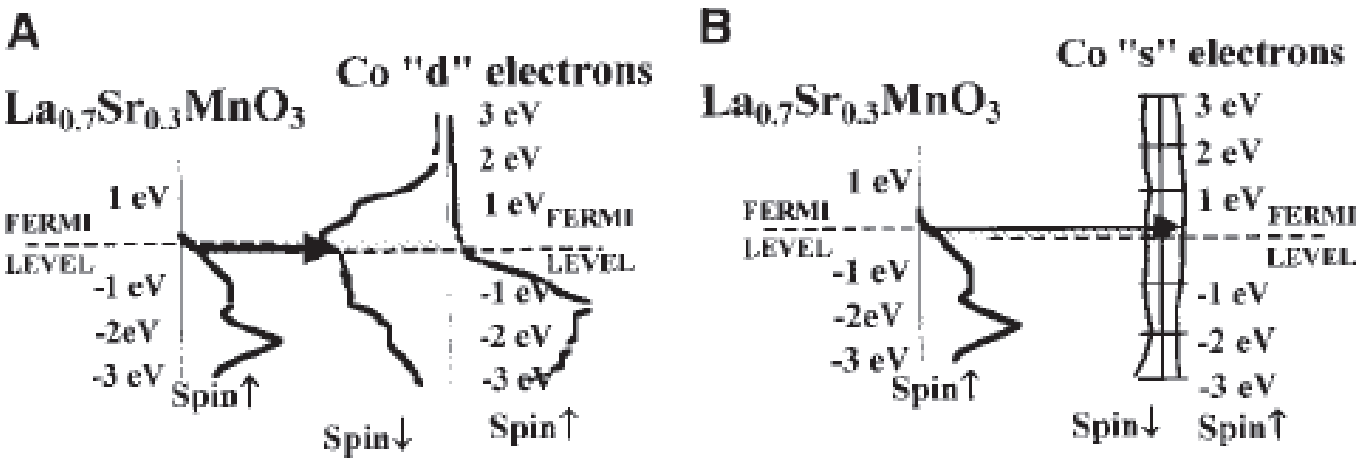

Electron injection from majority band

Electron jumped to minority band

With Al insertion >2nm, resistance increases, rectification emerges, and MR sign reversed at positive biases.

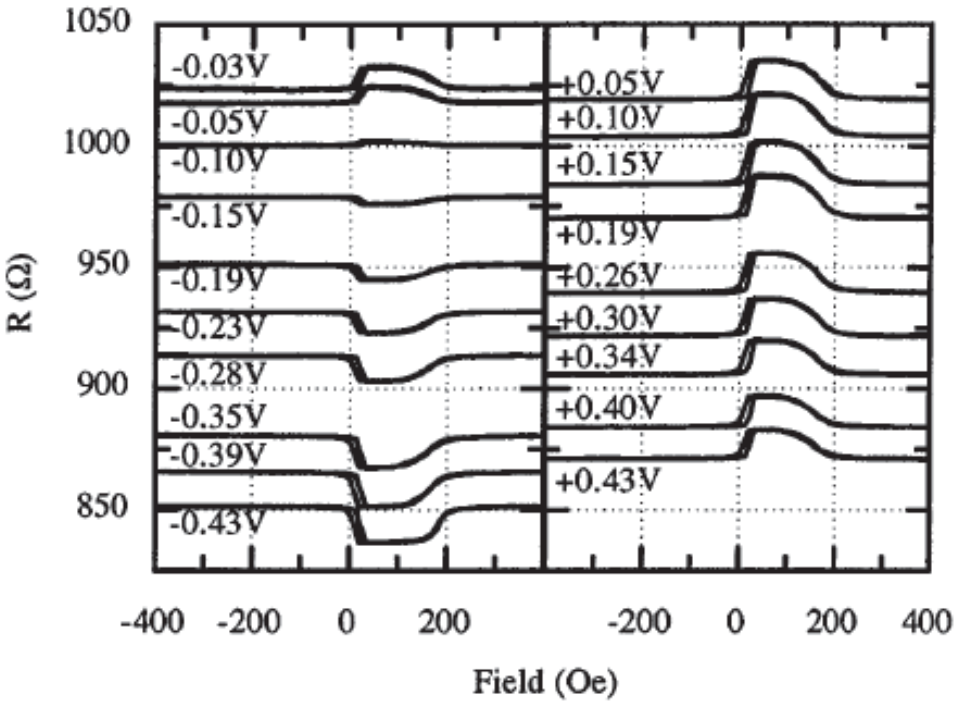
APL 104, 262402 (2014)

# Interfacial bonding and s/d electrons



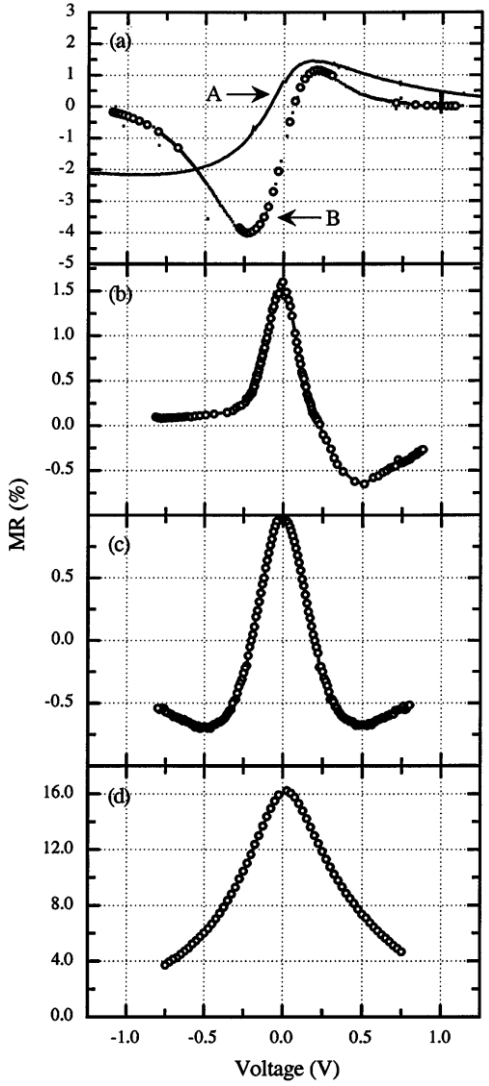
$10\ \mu m \times 20\ \mu m$,

# Ni80Fe20(12nm)/Ta2O5(0.5-1.5nm)/Al2O3(0.5-1.5nm)/NiFe(8nm)




$$\frac{\Delta R}{R} = \frac{R_{AP} - R_P}{R_{AP}} = \frac{2P_1P_2}{1 + P_1P_2}$$

PRL 82, 616 (1999)




A: Ta0.5/Al0.5

B:Ta0.75/Al0.75

C: Al0.5/Ta0.5

D: Ta0.5

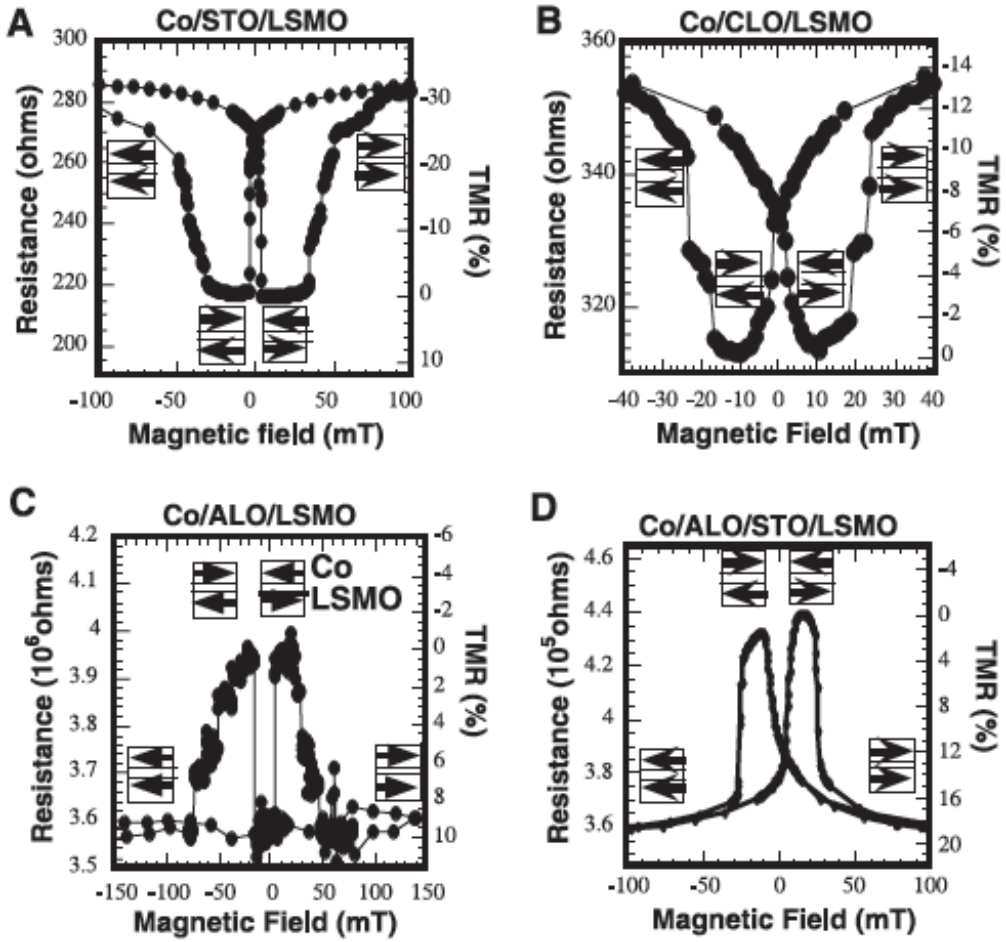
E: Al1.25

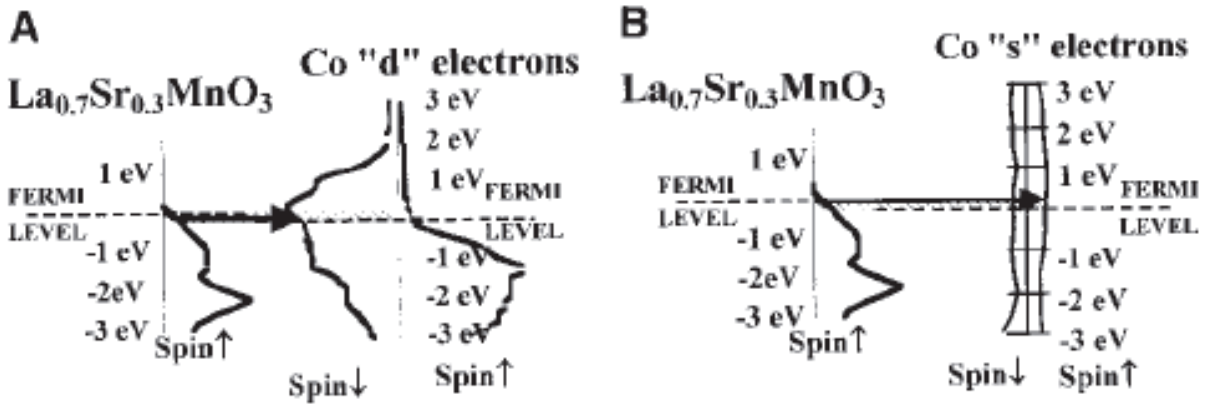
Inverse MR when Ta is positively biased.

Ta2O5/electrode shows reversed spin polarization and can be changed by bias.

S, d bonding.

# LSMO(35nm)/STO(2.5nm)/Co(30nm)/Au(5nm)



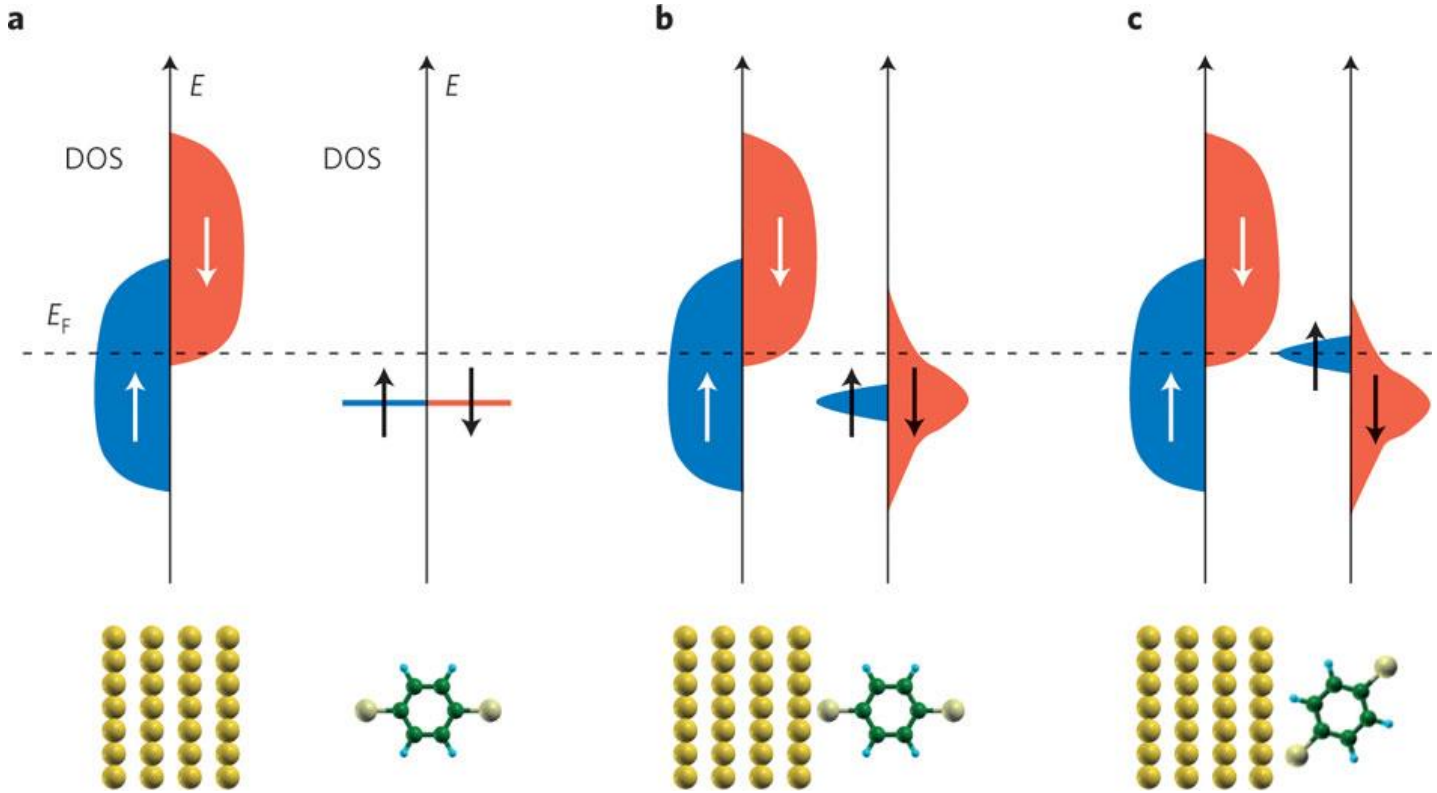




d electrons carry spin.

s electrons won’t carry spin.

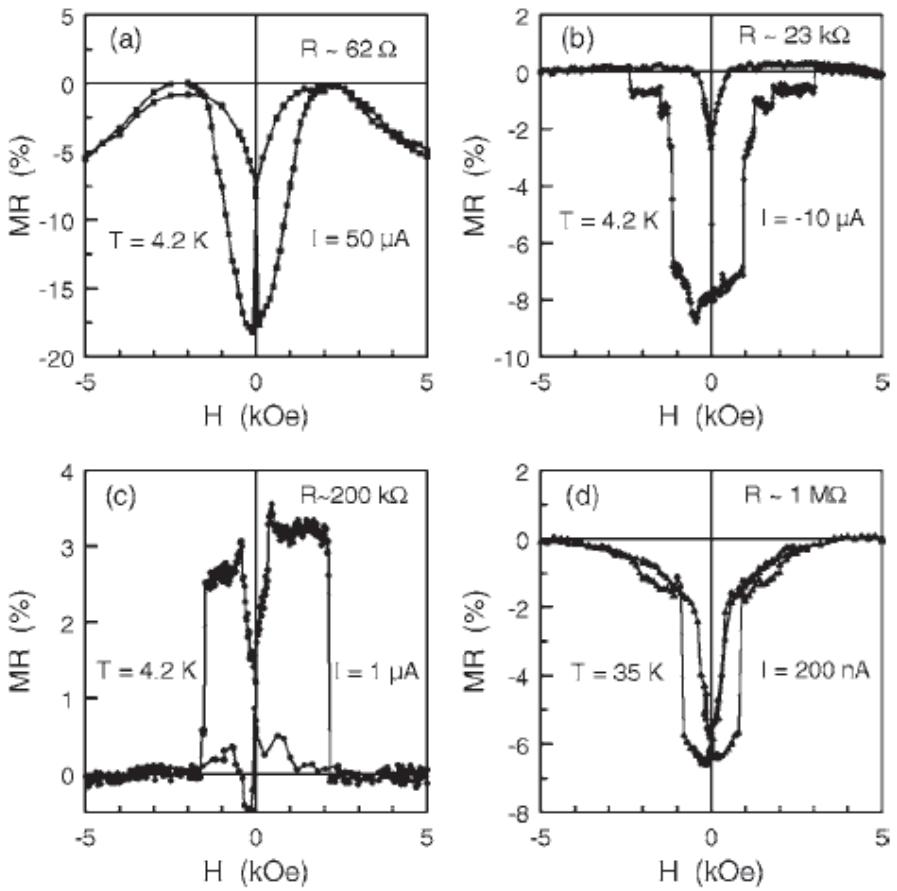
Science 286, 507 (1999)

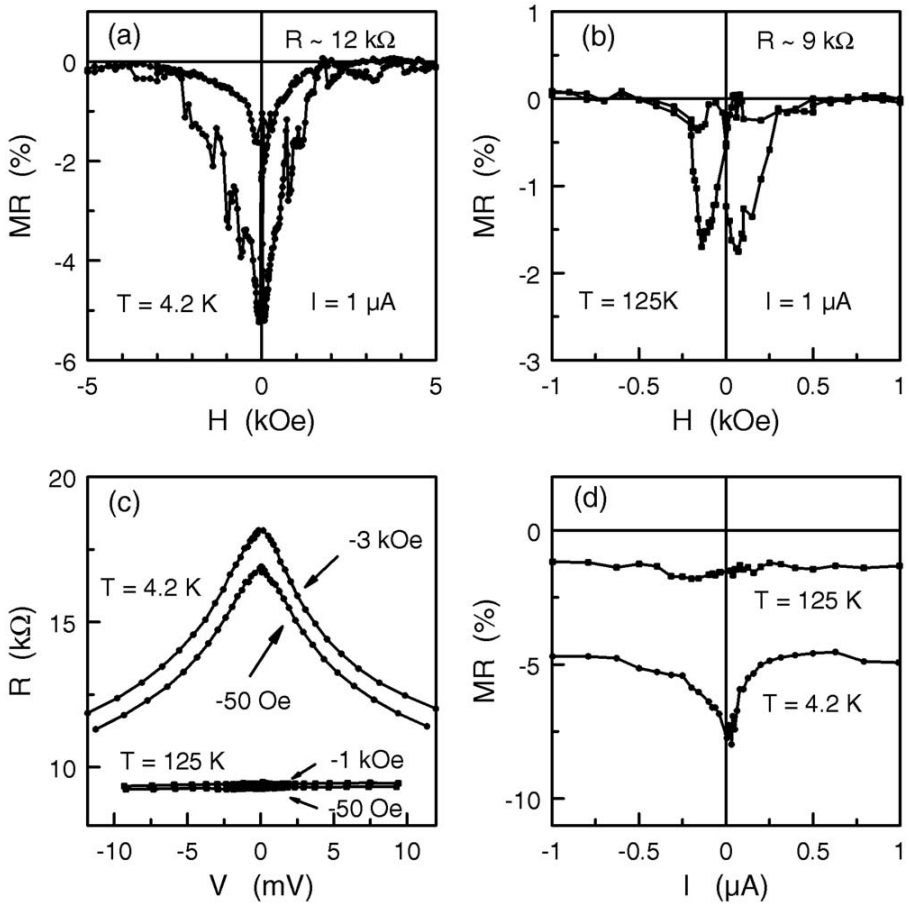
# Interfacial spin hybridization



$1-2\ mm^2$

# LSMO(100nm)/Alq3(150nm)/Co(10nm)/Al(10nm)



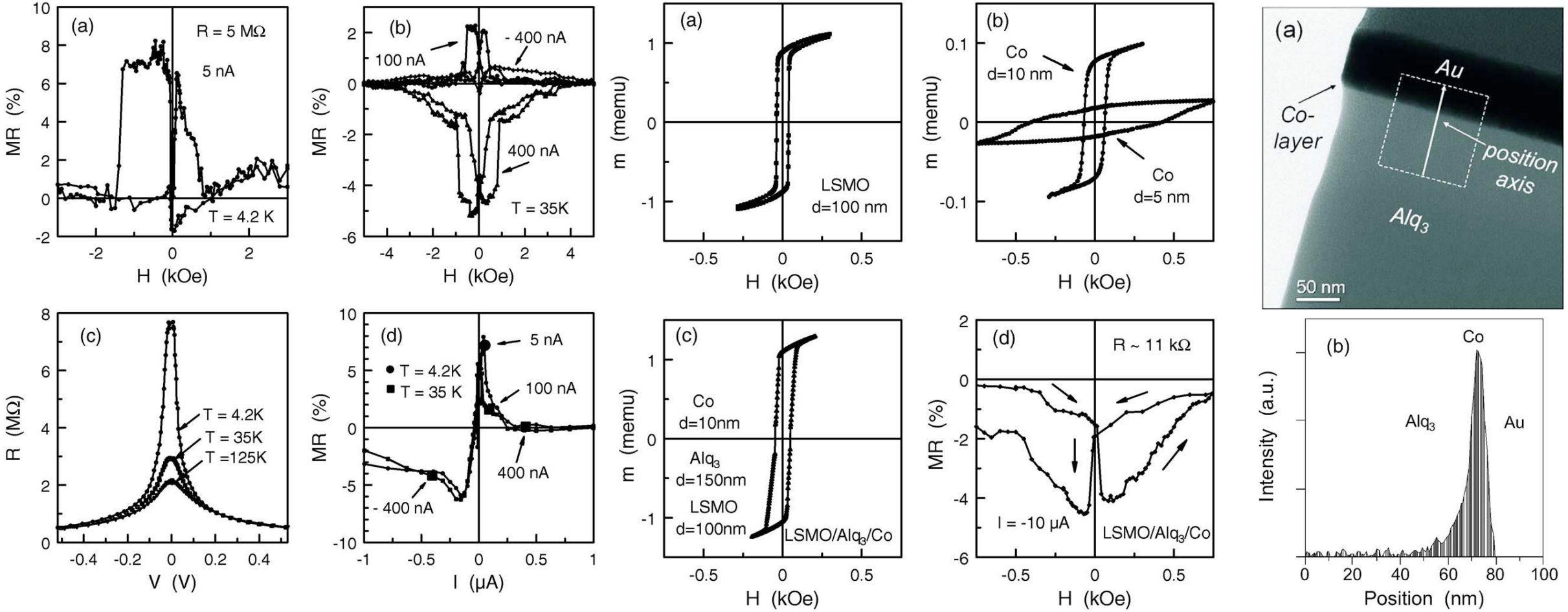

Different junctions: R ranges huge!

JAP 103, 093720 (2008)

80% samples show negative MR, symmetric IV

$1-2\ mm^2$

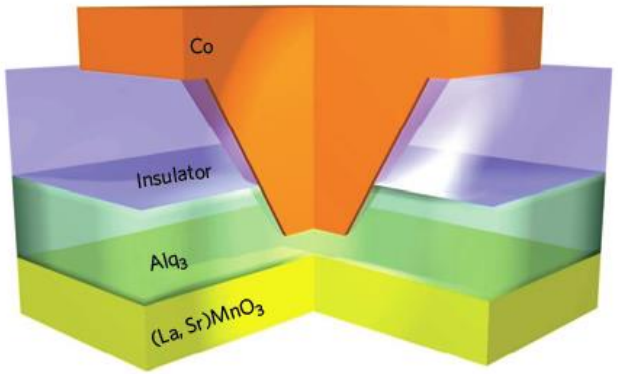
# LSMO(100nm)/Alq3(150nm)/Co(10nm)/Al(10nm)

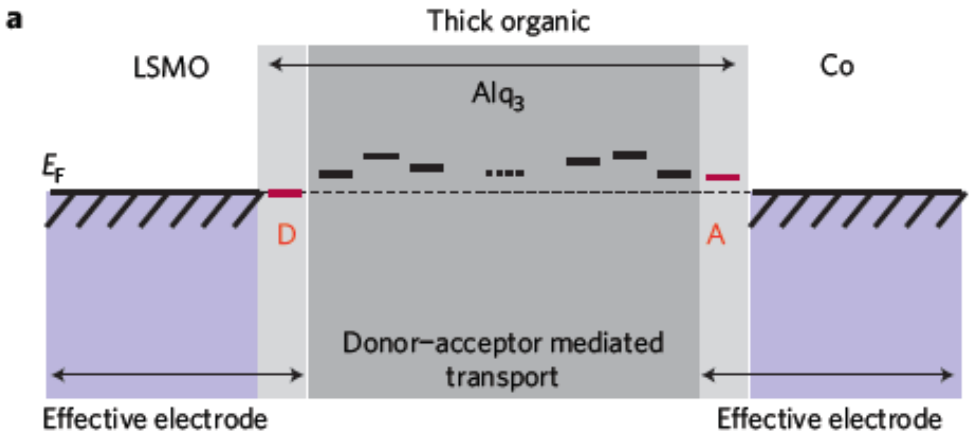


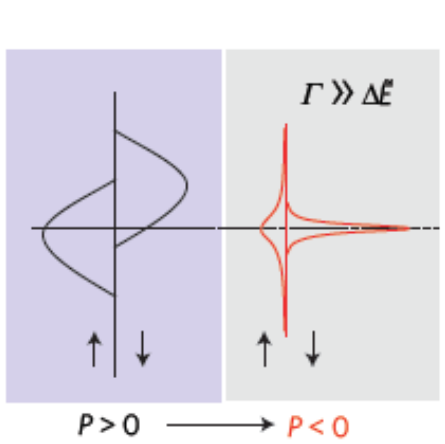

Some: MR sign changes with polarity. Thinner Co, bigger Hc.

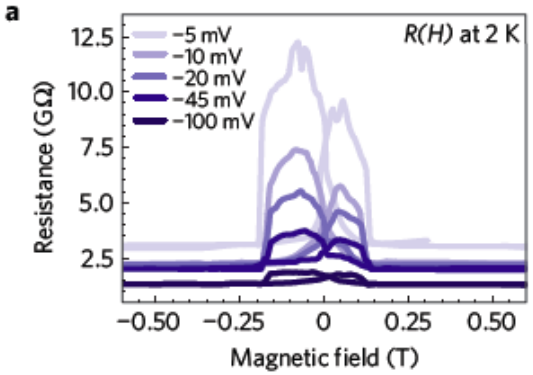
JAP 103, 093720 (2008)

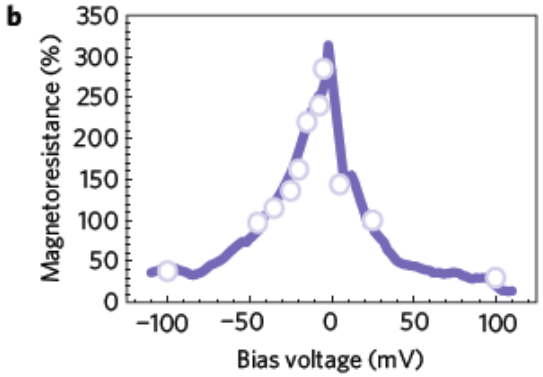
# LSMO/Alq3/Co

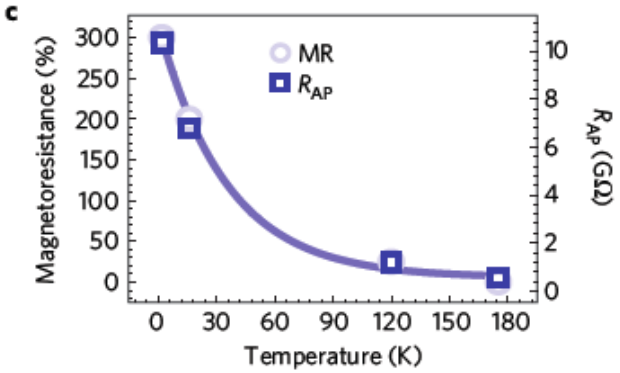



$$\mathrm{TMR} = \frac{2P_L{}^* P_R{}^*}{1 - P_L{}^* P_R{}^*}$$

with $P^* = -\dfrac{\Gamma^\uparrow - \Gamma^\downarrow}{\Gamma^\uparrow + \Gamma^\downarrow}$ in the $|\Gamma| \gg |\Delta\tilde{E}|$ limit

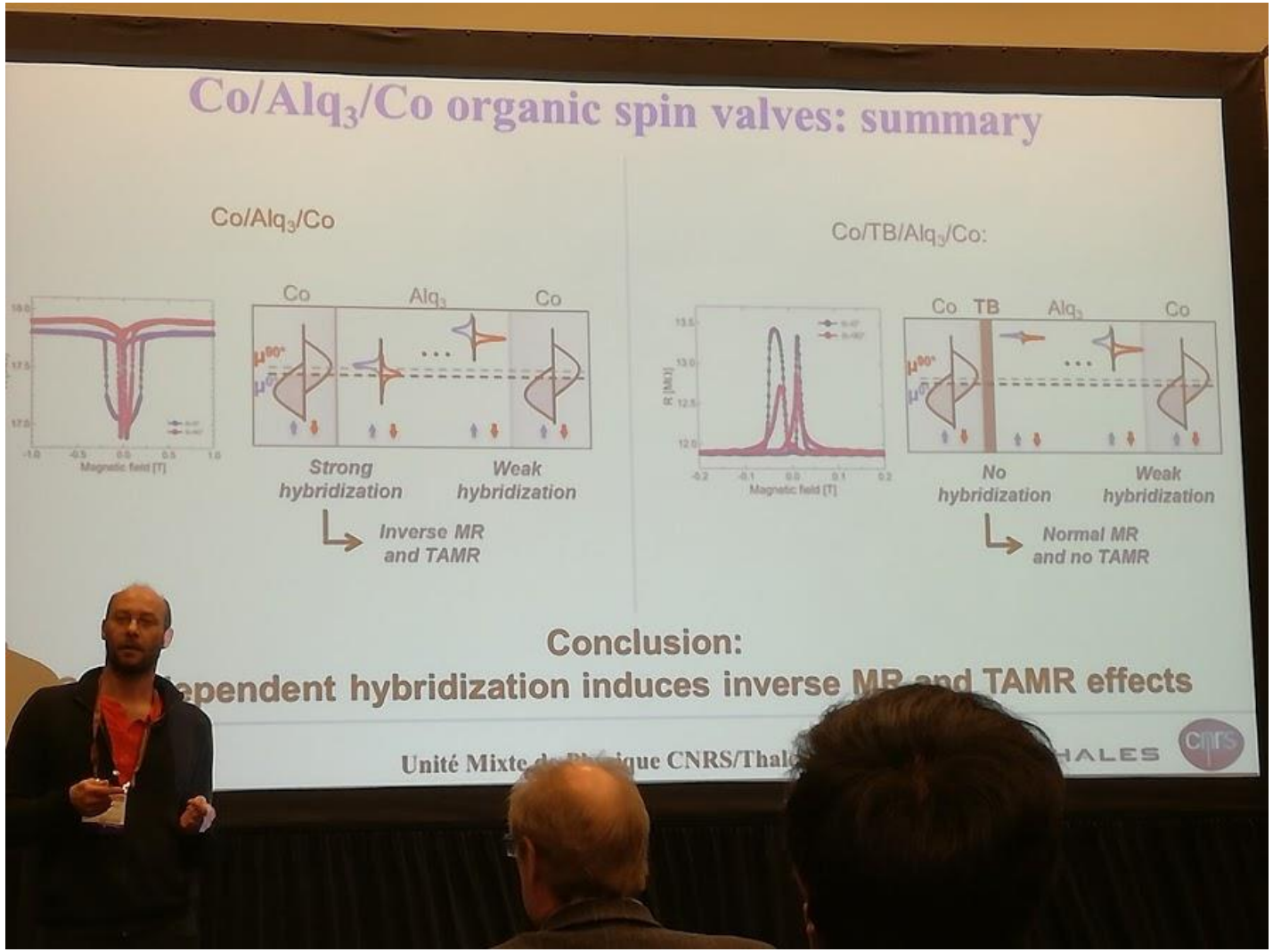
and $P^* = \dfrac{\Gamma^\uparrow/\Delta\tilde{E}^\uparrow - \Gamma^\downarrow/\Delta\tilde{E}^\downarrow}{\Gamma^\uparrow/\Delta\tilde{E}^\uparrow + \Gamma^\downarrow/\Delta\tilde{E}^\downarrow}$ in the $|\Gamma| \ll |\Delta\tilde{E}|$ limit

<10nm junction: positive MR

Strong bias and temperature dependence.

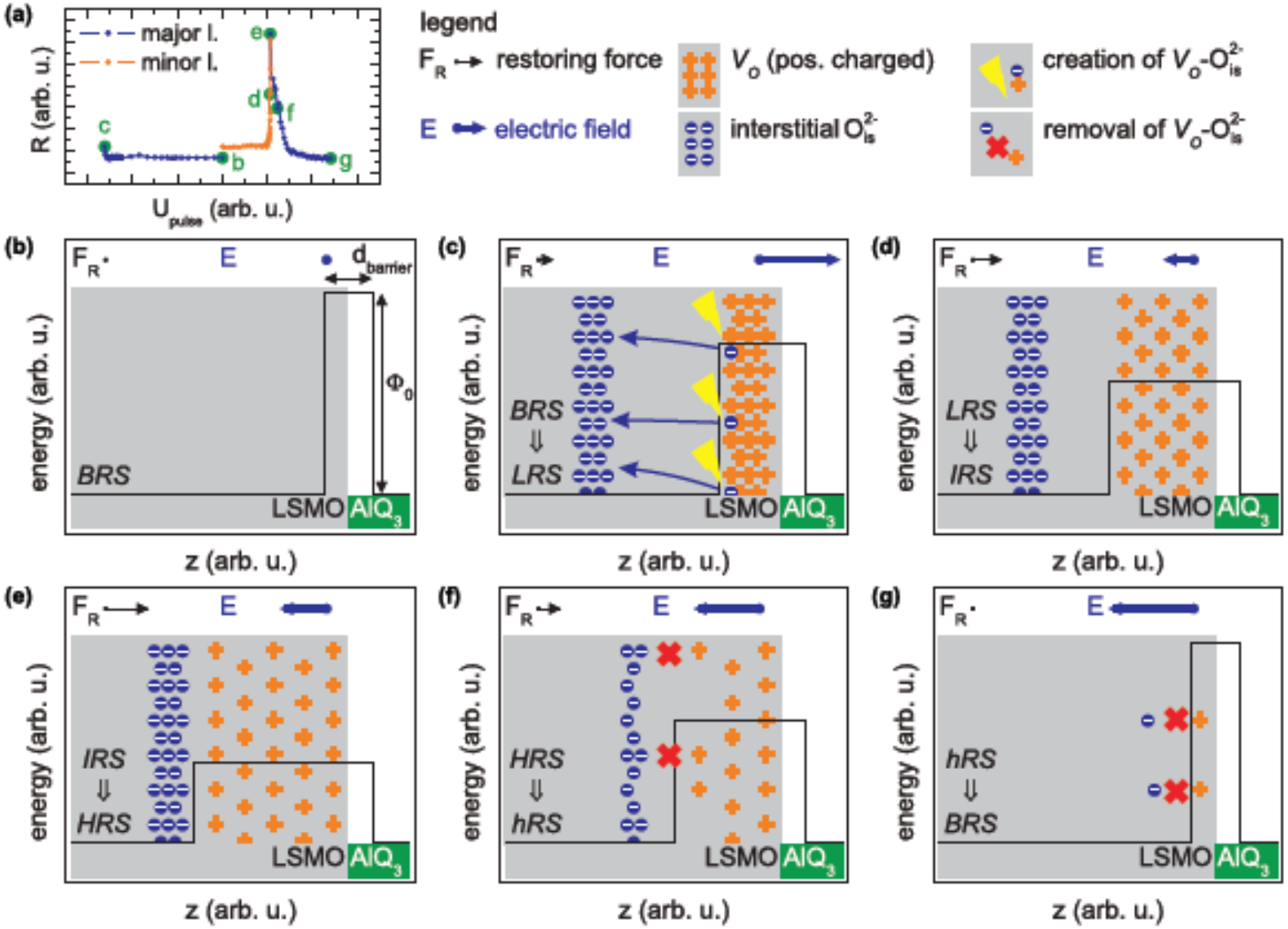
JAP 103, 093720 (2008)

# Hybridization induced MR inverse at Co/Alq3

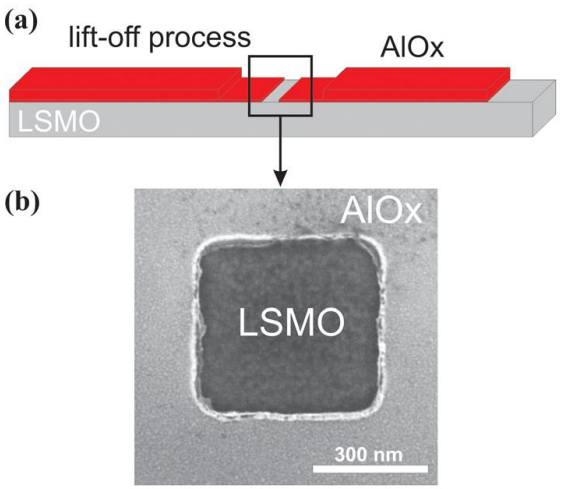



MR sign was reversed by inserting a layer between Co and Alq3

# oxygen vacancy at LSMO interface

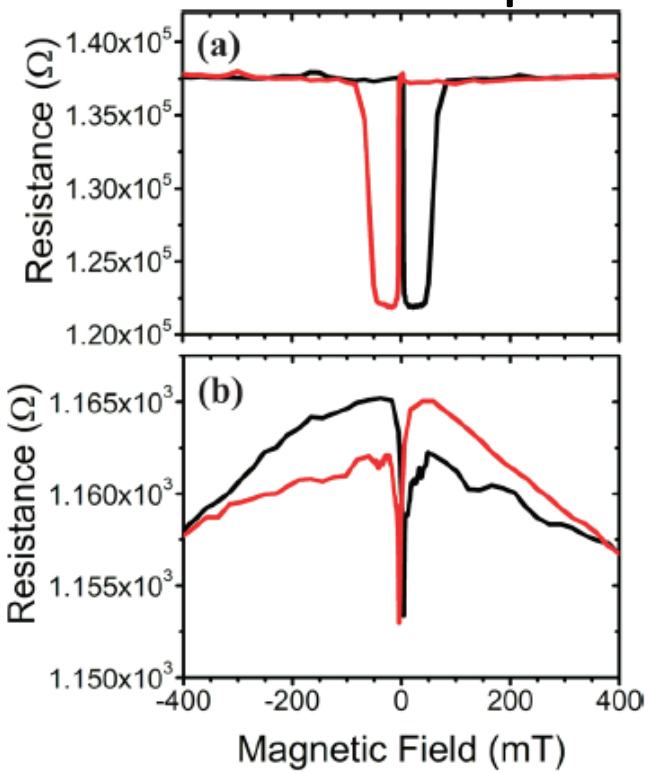


# LSMO(20nm)/Alq3(12-60nm)/MgO(3nm)/Co(30nm)/Ru(10nm)



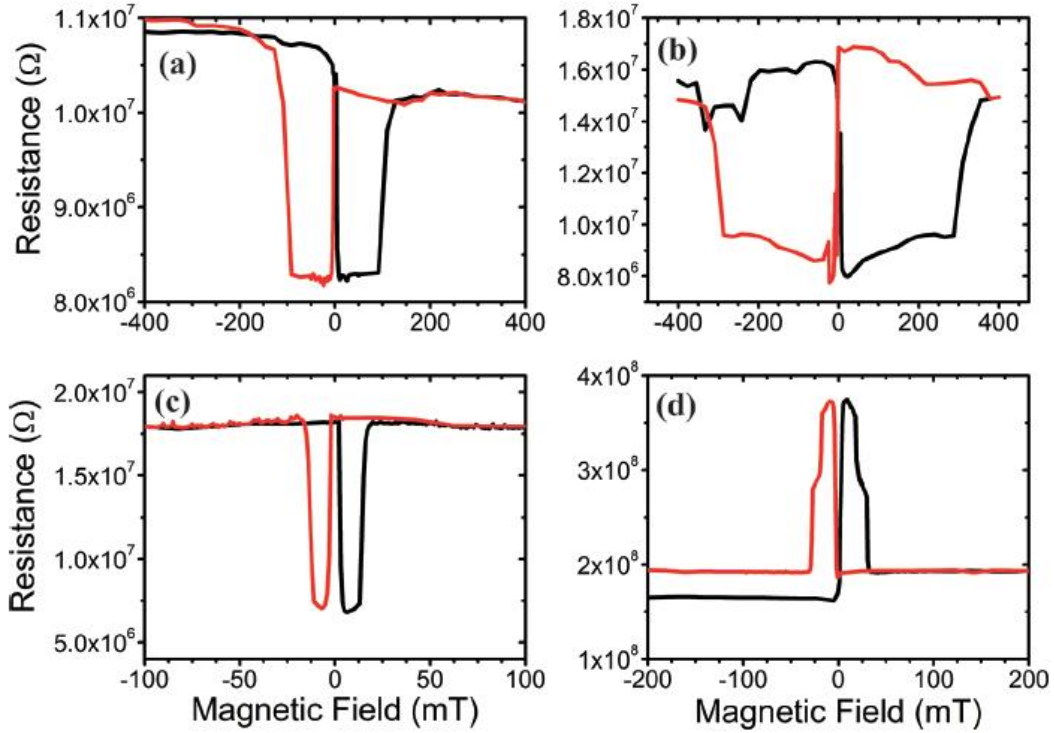

Submicron sample, 60% no pinhole; others show only one pinhole.

60nm Alq3




12nm Alq3

$200 \times 100\ \mu m^2$

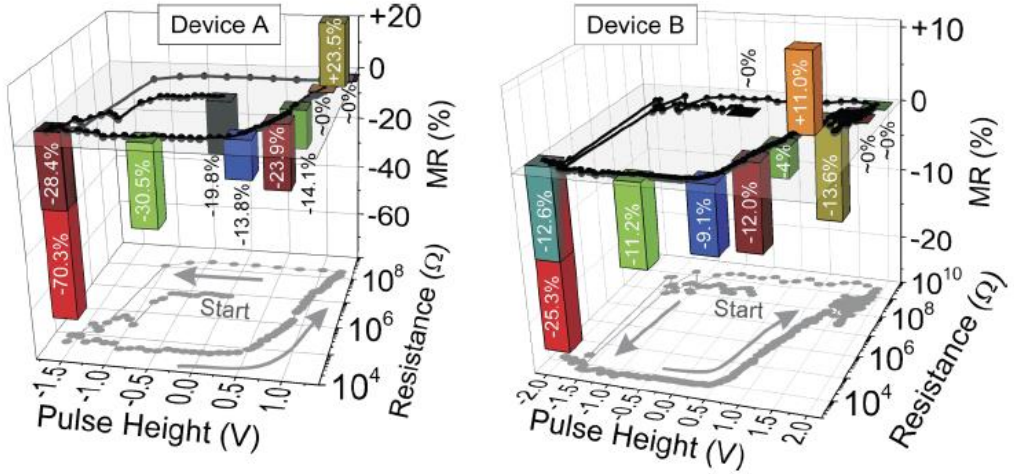



$500 \times 500\ nm^2$

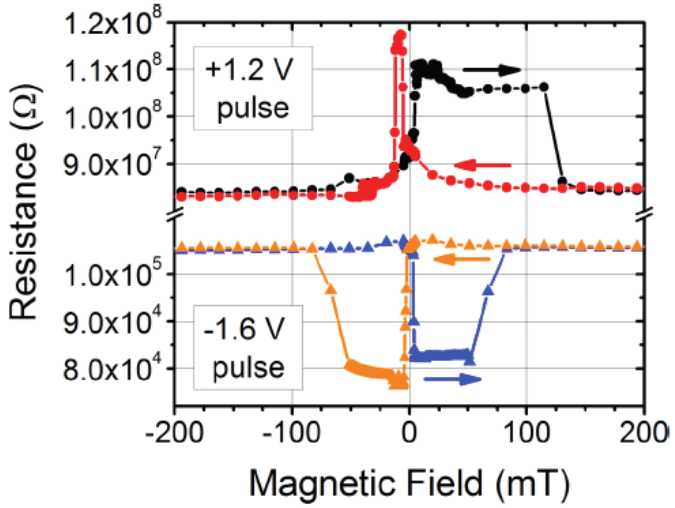
12nm Alq3

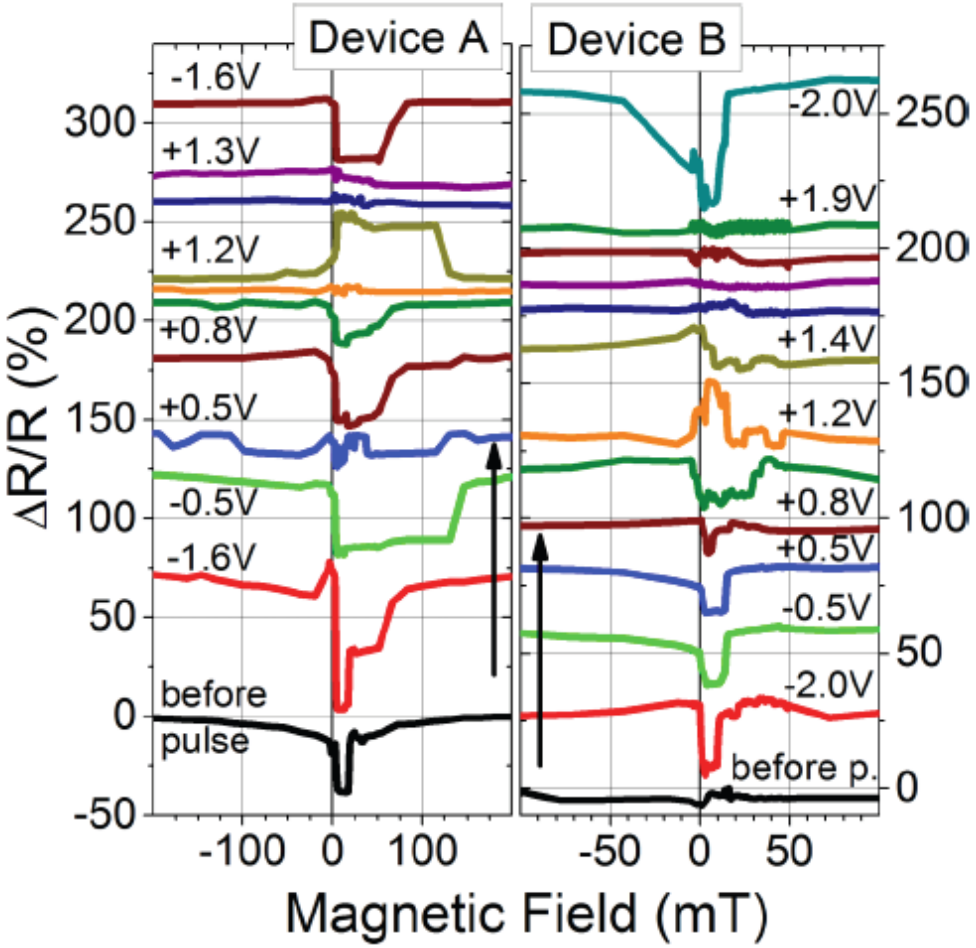
Appl. Phys. Lett. 106, 102403 (2015)

# LSMO(20nm)/Alq3(12-60nm)/MgO(3nm)/Co(30nm)/Ru(10nm)



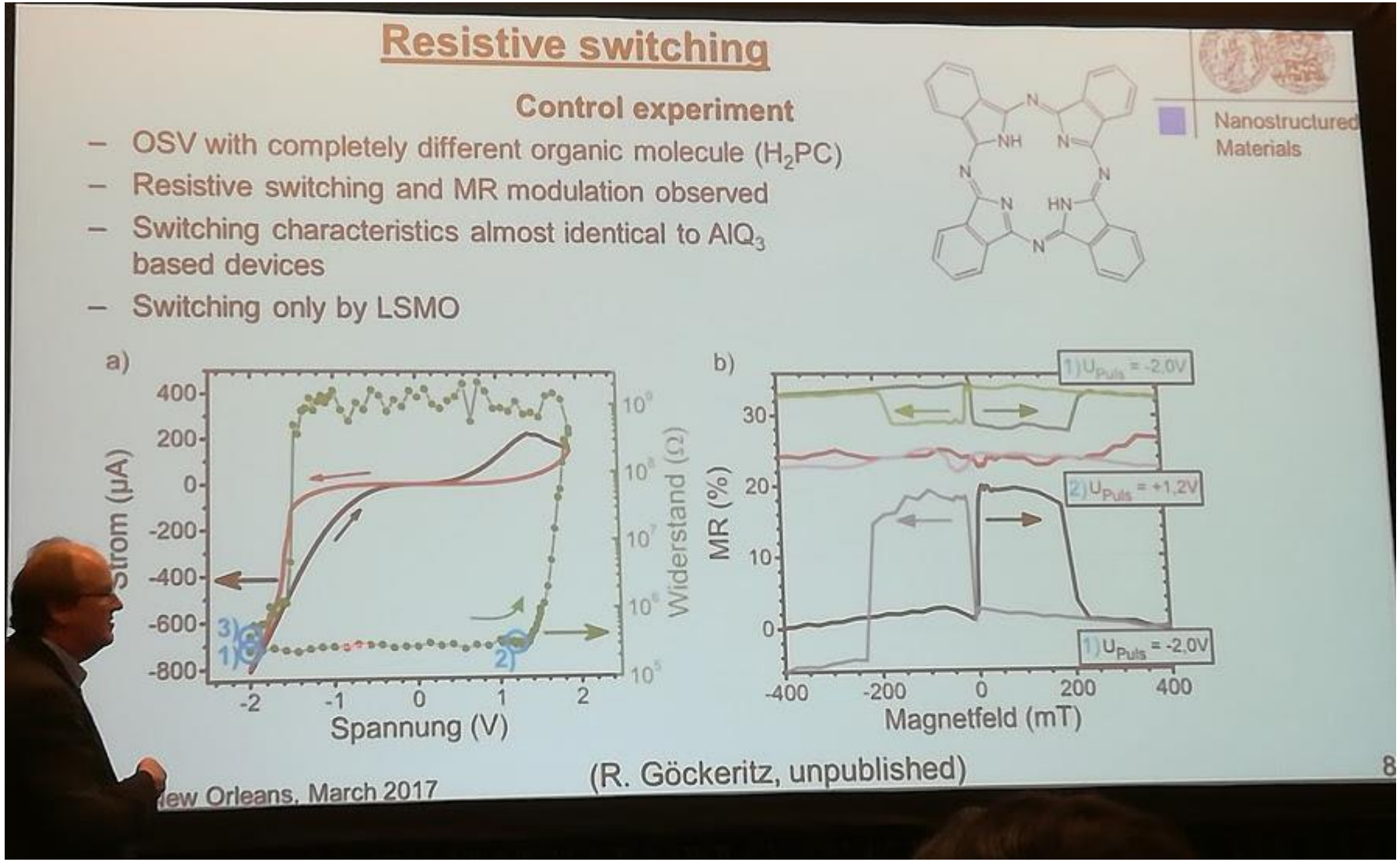

RS and MR reversal happens at the LSMO interface.



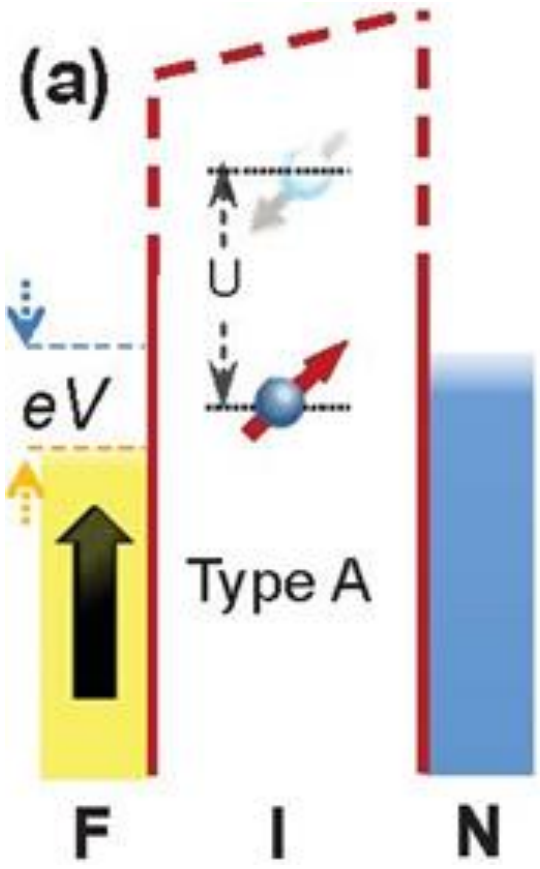

AIP Advances **6**, 045003 (2016)

# Replace Alq3 by H2PC

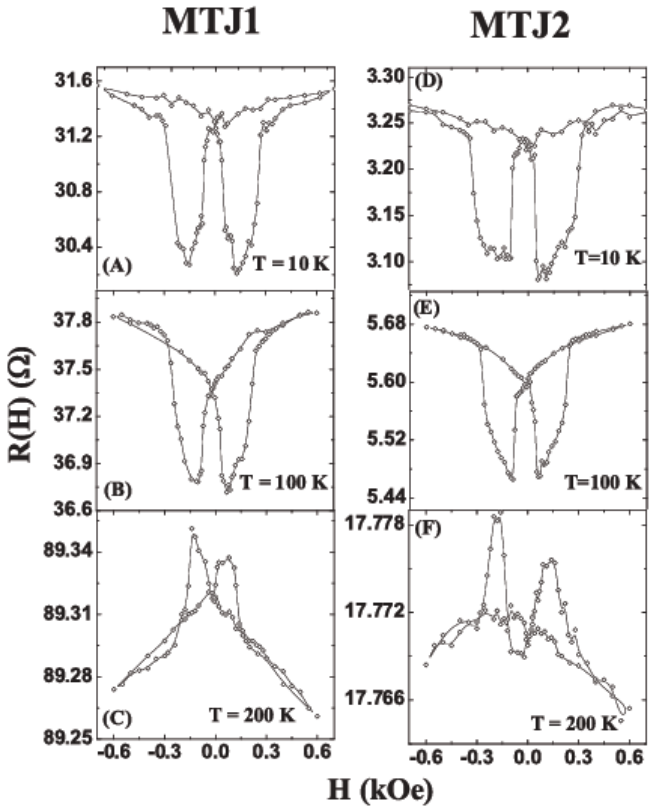


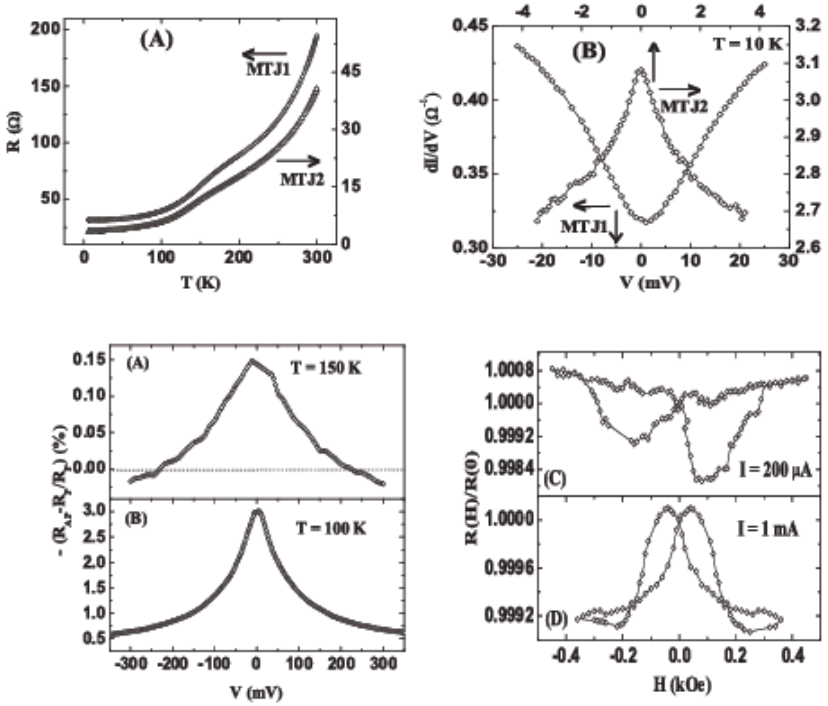

RS and MR sign reversal observed

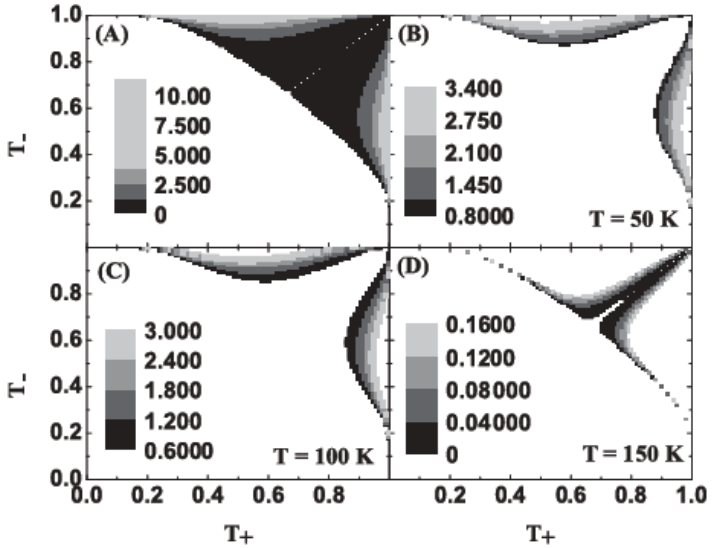
# Pinholes and localized states in barrier



# Ballistic magnetoresistance through pinholes




$$T_P = \frac{2\gamma_+}{(1+\gamma_+)^2} + \frac{2\gamma_-}{(1+\gamma_-)^2},$$

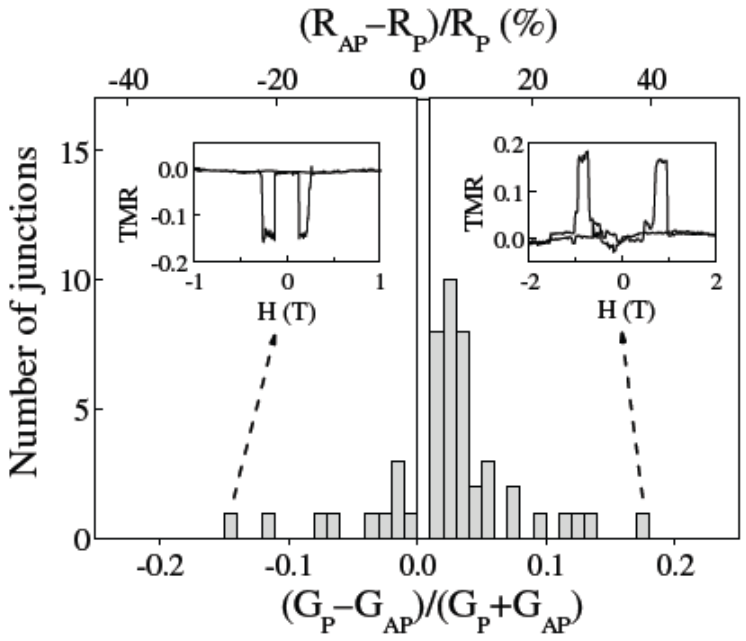
$$T_{AP} = \frac{4\sqrt{\gamma_+\gamma_-}}{(1+\sqrt{\gamma_+\gamma_-})^2},$$

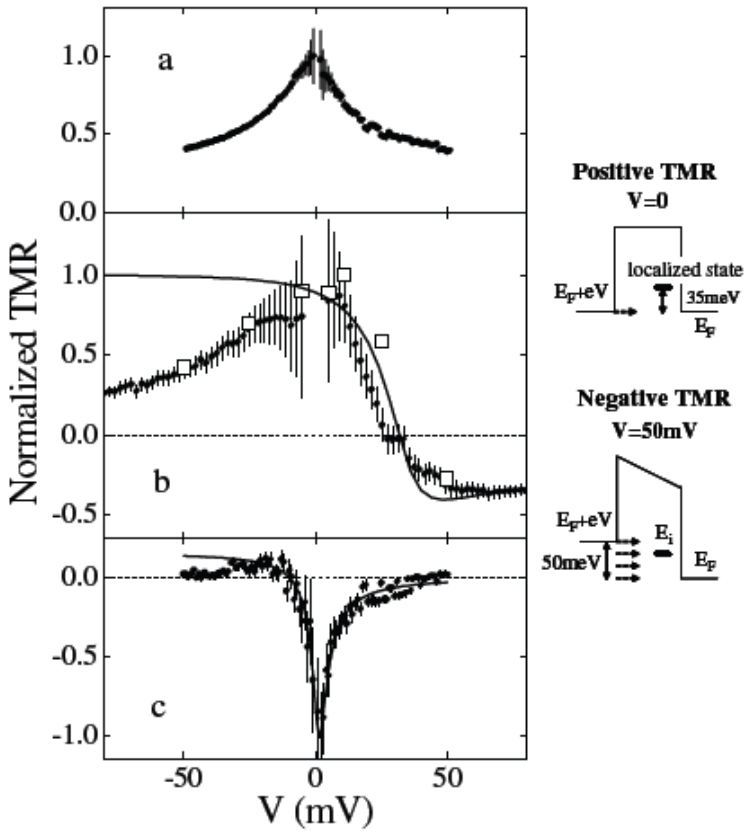
At higher bias, ‘‘hot electron’’ transport through the pinholes results in heat dissipation within the nanocontact region just outside the ballistic channel. The backscattering into the narrow channel increases due to larger phonon density of states at the nanocontact.

PRL **96,** 026601 (2006)

0.01 $\mu m^2$

# Ni/NiO/Co: Resonant tunneling through an impurity state



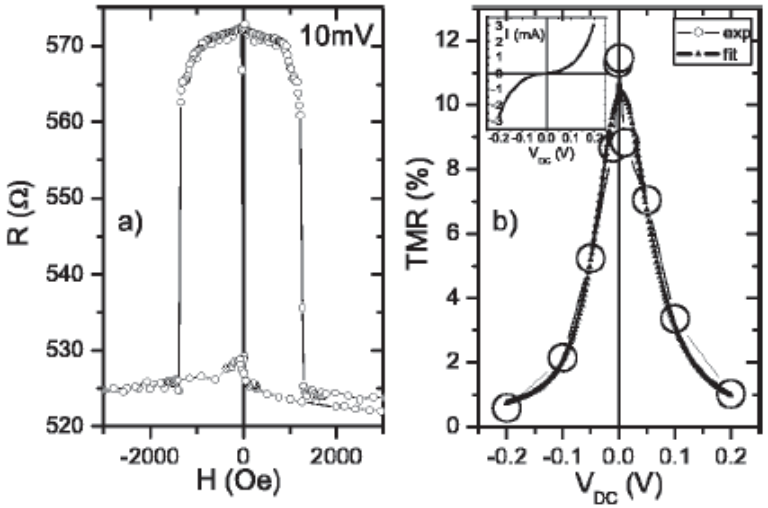

Big area will average out the impurity state position distribution and result in small positive MR effect.

$$G(E) = \frac{4e^2}{h} \frac{\Gamma_1 \Gamma_2}{(E - E_i)^2 + (\Gamma_1 + \Gamma_2)^2}$$

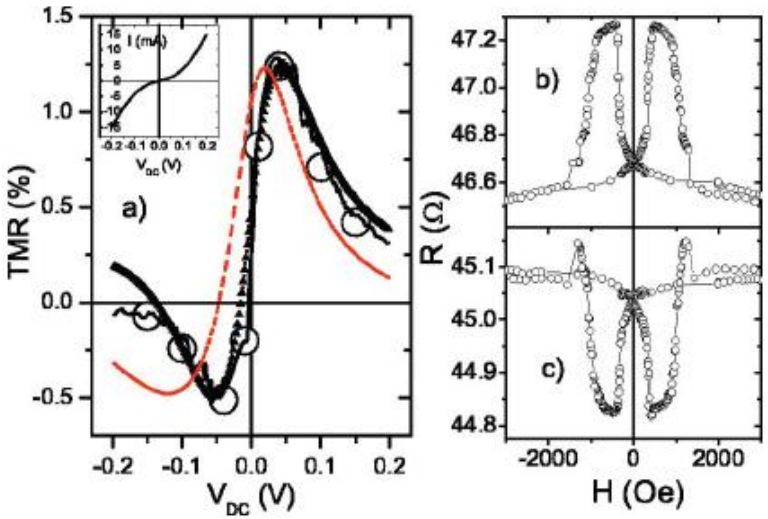
the energy of a localized state lies close to the $E_F$ and resonant tunneling dominates direct tunneling

PHYSICAL REVIEW letter 90, 186602 2003

# Resonant tunneling through a midgap defect band




8-$\mu$m$^2$ MnAs/AlAs (4 nm)/MnAs



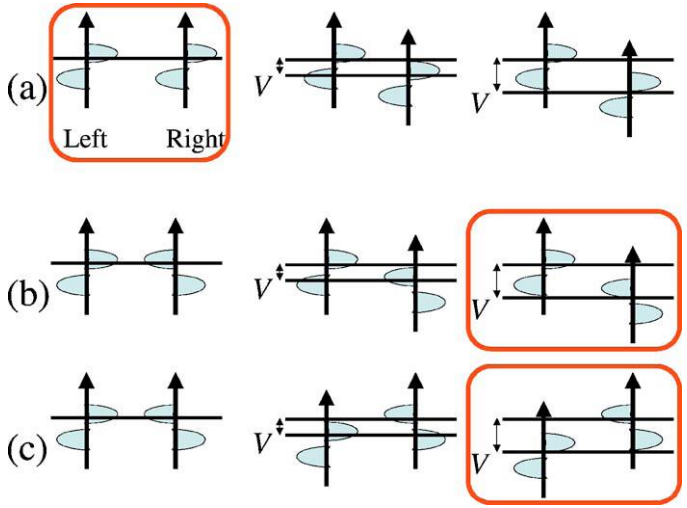

16-$\mu$m$^2$ MnAs/GaAs (7.5 nm)/MnAs

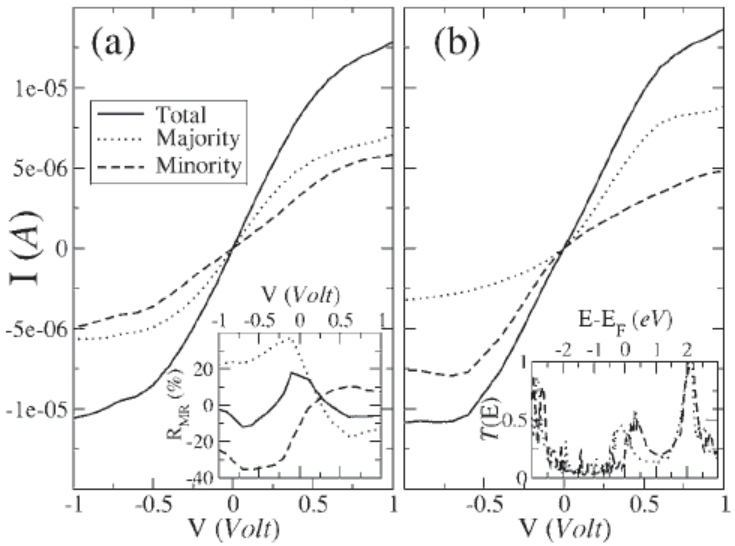
$$G_{\sigma\sigma'}(\epsilon-\epsilon_c)=\frac{4e^2}{h}\frac{\Gamma_{L\sigma}\Gamma_{R\sigma'}}{\Gamma_{L\sigma}+\Gamma_{R\sigma'}}\times\frac{\Gamma_{L\sigma}+\Gamma_{R\sigma'}+W}{[2(\epsilon-\epsilon_c)]^2+[\Gamma_{L\sigma}+\Gamma_{R\sigma'}+W]^2}$$

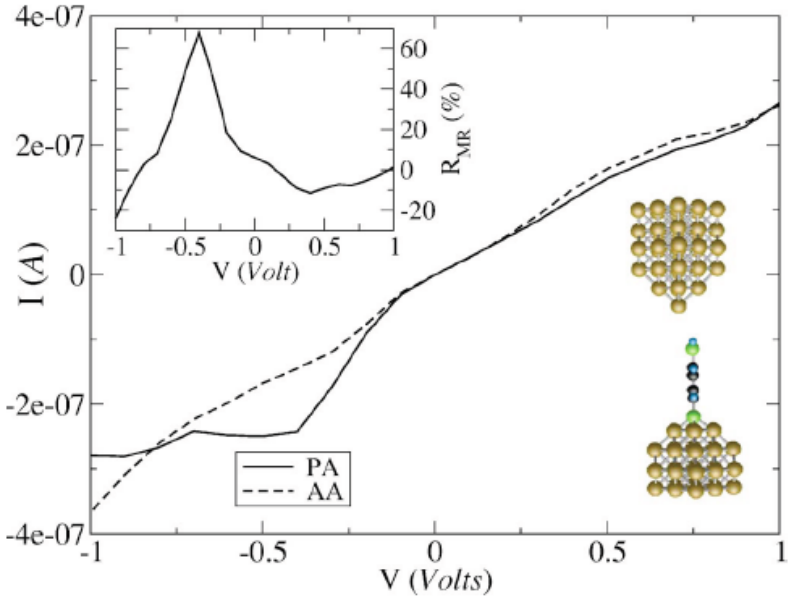
Thicker one benefits resonant tunneling compared with direct tunneling.

PHYSICAL REVIEW B **72**, 081303R 2005

# Resonant tunneling using Ni tip STM




MR show sign reversal with bias.

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